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Results of the REFLEX (Return Flux Experiment) Flight Mission
NASA Contract NAS5-32454
FINAL REPORT

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Experimental Rationale and Instrumentation

On January 16, 1996, the SPARTAN satellite was deployed by the Space Shuttle for a 40 hour upper-atmosphere mission to acquire both information on the scattering of gases released from a spacecraft as well as direct atmospheric compositional data. The experiment was carried out by instruments assembled in the REFLEX package containing, among other components, a sophisticated mass spectrometer and equipment to allow controlled release of argon and krypton gases for performing the return gas-flux studies.

The REFLEX mass spectrometer was designed, built and calibrated by the University of Minnesota under NASA contract NAS5-32454. There are four major parts to the instrument: the electron impact ion source to ionize neutral particles, an electrostatic energy analyzer for energy and velocity separation, a magnetic mass analyzer of Mattauch-Herzog geometry for mass separation, and an ion detector system containing three counting multipliers and an electrometer. Because of this detector arrangement, the entire mass range was divided into low, medium, and high sections.

This experimental package was a derivative of instruments flown previously on upper atmospheric satellites such as those in the Atmospheric Explorer Program. A special addition was made to the instrument to allow separation not only of mass but also of the energy of the incoming particles. An electric energy analyzer ahead of the permanent magnet permitted such a separation of ambient gases or of gases reflected from atmospheric constituents from those accommodated on spacecraft walls. This particular feature provided for the first time the opportunity to study gases released under well-controlled conditions from the free-flying SPARTAN spacecraft. As they were reflected from ambient particles, consisting mainly of O and N₂, the returned flux to the mass spectrometer was to be determined.

Results: Data Acquisition and Interpretation

Several problems arose during the mission which caused great difficulties for interpretation of the data. One important requirement for a successful mission was the proper orientation of the SPARTAN spacecraft with respect to the satellite velocity. To measure ambient atmospheric gases directly, the instrument had to be pointing within a few degrees —preferably along— the velocity vector, typically called the ram position. Unfortunately the mass spectrometer was never positioned directly into the ram. The closest the instrument got to the ram direction was 11°, and since the instrument has an acceptance angle of less than 10°, no direct measurements of the ambient atmosphere were obtained (although it is somewhat puzzling that thermal angular scatter did not result in at least some indication of high-speed atmospheric species, even at 11° offset). This orientation offset was particularly unfortunate since the major atmospheric constituent at these altitudes —approximately 300 km— is atomic oxygen, which can be detected directly only in the "fly-through" mode. However some atmospheric inert-gas data, including helium, were obtained in another operational mode which does not depend as strongly on the pointing accuracy of the mass spectrometer (see Figs. 11 and 12 in Appendix A).

An unanticipated mass-identification problem compromised the mass centering of the instrument in its middle-mass range. When in orbit it was initially necessary to determine the precise location of the different mass numbers of the ions to be measured by tuning certain electrical parameters. A procedure was established to fix the operational parameters of the mass spectrometer for a particular gas and find the center of the mass peak associated with that gas. Argon, with a mass of 40 amu for its most abundant isotope, was one of the gases chosen to determine the mass scale since it is known that argon is a constituent of the upper atmosphere. Unfortunately, a large ion current was also present at mass 39, which confused the centering procedure and consequently established an incorrect mass scale for the important middle mass section of the spectrometer. It is now believed that the ion currents observed at mass 39 and other nearby masses were due to an unexpectedly large outgassing of the SPARTAN spacecraft immediately after attaining orbit.

A significant and still unexplained instrumental anomaly involved the energy centering of the mass spectrometer. The center of the energy peak drifted and moved a significant amount during the mission, resulting in a signal at the detector which was difficult to separate from background signals. Post-flight investigations have not established the cause of the drift; it appears to have been due to as yet unknown processes. This drift was apparently the major cause of the failure to unambiguously detect returned argon and krypton released by the satellite, required for analyzing the return-flux properties of the atmosphere. Although meeting the spacecraft pointing specifications would have been desirable for the detection of return-flux signals, this additional problem of orientation offset should have had a comparatively minor effect on these particular measurements since the return flux should have decreased only as the cosine of the offset angle.

Because of the major problems noted above, as well as other, more minor difficulties, only very limited amounts of return flux data were acquired. The drift in the energy analyzer made it impossible to obtain reliable return-flux krypton data. After half of the orbits were completed, a new reset signal was given to the entire REFLEX instrument package and another attempt was made to acquire an additional set of atmospheric and released-gas data. However, although the mass centering was now done properly, the energy analyzer drift still reduced return-flux signals to very low levels where statistical noise was significant.

Summary

The numerous problems occurring in this first flight of the REFLEX experiment, both in the spacecraft and with the instrument package, seriously constrained the acquisition and analysis of data and severely limited the interpretation of the data that were obtained. Of these, the ambient helium measurements appear to be the most promising. They are summarized and discussed in Appendix A. Further analyses could be attempted to establish the correct values for the energy centers as they varied during the mission. In addition, an extensive laboratory recalibration on a high-speed beam system could in principle provide corrections to be used in analyzing and interpreting the returned data set. The unknown malfunction which generated the energy drift needs to be understood and corrected before the REFLEX experiment is reflown; some hardware modification, or at least retuning, is likely to be required.

Future prospects

Although the instruments did not return most of the data sought in this mission, the availability of calibration facilities for regular and high-speed gases built or modified for the REFLEX experiment, together with post-flight analysis and correction of the problems encountered and the limited data acquired in this flight, should make a re-flight of this experiment much more likely to succeed.

APPENDIX A

**Examining the Results
of the
REFLEX
(Return Flux Experiment)
Flight Mission**

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NASA/Goddard Space Flight Center

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Mentor
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Examining the Results of the REFLEX Flight Mission

**Summer Institute on Atmospheric and Hydrospheric Sciences
NASA/Goddard Space Flight Center**

**Participant, Diana Orrick, Florida State University
Mentor, Dr. Heidi K. Manning, USRA/Code 915**

The Return Flux Experiment (REFLEX) was designed to combine a mass spectrometer and an energy analyzer to measure atmospheric species in the thermosphere to study the outgassing properties of space objects.

The instrument was developed at the University of Minnesota. Mr. John Morton, Drs. Konrad Mauersberger, Heidi Manning and Brad Johnson were primary developers with a support team. The REFLEX instrument was mounted on the Spartan 206 sub-satellite. The free-flying satellite was deployed January 14, 1996 by the shuttle arm of STS-72, orbiting ahead of the shuttle for a cleaner environment and retrieved 40 hours later. The REFLEX instrument released a gas mixture of argon (Ar) and krypton (Kr) and then measured the amount and energy of the returning Ar and Kr gas. In addition to Ar and Kr, the REFLEX instrument possesses the capability of measuring gas densities of the ambient atmosphere [Figure 1].

The incoming neutral gas was ionized passing through the ion source and directed through the energy analyzer for energy separation. Then through the use of a mass analyzer directed to a focal plane where the particles could be detected at a count rate, for a given mass and energy [Manning, 1995] [Figure 2].

In order to begin to analyze the REFLEX returned densities, the summer student examined a global thermospheric model based on mass spectrometer and incoherent scatter data, (MSIS). MSIS was developed in 1977 by A. E. Hedin of the Planetary Atmospheres Branch of NASA/Goddard. The model combines in situ mass spectrometer data from eight satellites, numerous rocket probes, and five ground-based incoherent

scatter stations to provide predictions of temperature and densities of Ar, H, He, N, N₂, O, and O₂ [NSSDC, 1996].

The most current version of the MSIS model, MSISE90, is available to run on-line via the Internet (<http://nssdc.gsfc.nasa.gov/space/model/models/msis.html>) through the National Space Science Data Center. The site allows the entry of various parameters (date, time of day, geographic or geomagnetic latitude & longitude, altitude) and returns a listing of the gas densities as well as neutral temperature.

The work this summer focused on the REFLEX helium data while working with the MSIS model. The primary work of the summer student was to examine and compare the He density returned from the REFLEX experiment and MSIS model, between the mission elapsed hours of 13.5 through 22.0

The process of developing the comparison involved several stages.

Initially, information for 26 orbital positions were provided by Jim Morrissey of the Attitude Control & Stabilization Branch of the Special Payloads Division/Code 745.1 of NASA/Goddard [Figure 3]. Using the MSISE90 web site, a set of model outputs were generated to begin the comparison work with REFLEX. Dr. Johnson at Minnesota provided the formatted data files from the REFLEX mission [Figure 4].

Interactive Data Language (IDL) was used for data preparation, processing and graphing. IDL integrates an array-oriented language with numerous mathematical analysis and graphical display techniques to offer a time-saving programming alternative to traditional Fortran or C. The summer student had no prior experience with IDL.

The REFLEX flight data was given as a count rate which is converted to a density by a multiplicative factor. At this point ion source densities were produced [Figure 5].

Considering additional technological aspects, there is a difference in densities in the ion source and in the ambient atmosphere due to the forward motion of the spacecraft. This is known as the ram effect. Therefore, a correction was needed for the densities measured in the ion source to derive ambient densities (for MSIS comparison) [Fig. 6].

A detailed derivation of the ram effect correction is given by Von Zahn [Von Zahn, 1974]. This derivation assumes a constant instrument velocity and derives a velocity correction factor, $F(S)$ to be

$$F(S) = \exp(-S^2) + (\pi)^{1/2} * S[1 + \operatorname{erf}(S)],$$

where $\operatorname{erf}(S) = 2(\pi)^{1/2})^{-1} * \text{the integral from } 0 \text{ to } S \text{ of } \exp(-x^2)dx.$

Equating particle flux entering the source to the particle flux leaving the source the relationship between the ion source and ambient density is: $n_a = n_s/(T_a/T_s)^{1/2} * F(S)$ The $F(S)$ correction function was programmed and the results used to compare the MSIS output with the REFLEX data [Figure 7].

At this point, 99 REFLEX points were extracted between the mission elapsed hours of 13.5 through 22.0. The mission time segment was selected as it was the best He data acquired during the mission. At other times, the satellite was not positioned for optimal atmospheric measurements or the instrument sensitivity was low. The nine corresponding MSIS positions were then linearly interpolated for the initial graphical comparison plot. Finer resolution (per minute) of the orbital positions of the Spartan 206 was needed for the final MSIS comparison [Figure 8,9,10].

The data work then required an alternative method for processing the new orbital information through the MSIS model as the web site provided only for singularly input profiles. Working with Fortran programs of the MSIS86 model (recommended for altitudes at or above 300km) the summer student modified a test program which had hard-coded input data to use an input data file of parameters for the complete orbital information.

In order to build the input file, certain known parameters (year, day, UT, altitude, geographic latitude & longitude) would need to be provided along with certain unknown parameters (solar time, geomagnetic activity [A_p] indices, solar radio flux) to correctly run the MSIS86 model program.

An equation for calculating the solar time was found in an interactive driver

program provided with the MSIS86 files.

The geomagnetic activity indices and solar radio flux values were provided by the web site at the National Geophysical Data Center (NGDC) in Boulder, Colorado (<http://www.ngdc.noaa.gov>). Variations in the daily regular magnetic field occur due to regular solar radiation changes. Other changes can occur due to interaction of the solar wind with the magnetosphere or between the magnetosphere and the ionosphere. Solar radio flux changes gradually from day-to-day corresponding to the number of sunspot groups as the sun radiates radio intensity [NGDC, 1996]. MSIS requires consideration of these variations through the Ap geomagnetic activity index and solar flux parameters.

By the use of switches, the MSIS86 program could use an averaged daily Ap index value or a detailed Ap history. The summer student provided for both options in the input program development. The NGDC file listed Ap values for 3-hourly segments and a daily value for the arithmetic mean of the day's eight Ap values. The MSIS model program required this information according to the UT time being examined for the profile being processed. This required the summer student to develop a program which could (for the two different days of the mission) extract the NGDC data for the correct timeframe considered.

When all parameters were compiled and the input file developed, the previously hard-coded test file input was used to validate the output of the modified program. Using IDL once again, new graphs were created of the REFLEX and MSIS data [Figure 11].

The new graphs showed a marked improvement in the MSIS and REFLEX information. Although the REFLEX densities were measured lower than the MSIS output, the curve of the data was consistent with the MSIS. The graphics showed latitudinal peaks in the helium readings by REFLEX. This was expected from the winter hemispheric helium bulge owing to the exospheric transport of helium from warmer areas to cooler areas over the globe [Mayr et al. 1978].

Further analysis of the data will be conducted by Drs. Manning and Johnson.

Additional MSIS86 comparison will be possible from the complete output of the program developed by the summer student.

In addition to the computational work performed, the summer student participated in bringing an instrument down to vacuum pressure and 'baking out' the instrument to provide for a better vacuum. The instrument is to be used in laboratory testing. Delayed electronic work, due to pressing deadlines on the Cassini project prevented further laboratory exposure other than observational.

References:

Manning, H. K. , The development of a new Mass Spectrometer for Upper Atmosphere Research, *Physics Doctoral Thesis*, University of Minnesota, 1995

National Space Science Data Center World Wide Web Site,
<http://nssdc.gsfc.nasa.gov/space/model/models/msis.html>, 1996

Von Zahn, U., Composition Studies in the Thermosphere By Means of Mass Spectrometers, *Structure and Dynamics of the Upper Atmosphere F.* Verniani (Editor), Elsevier Scientific Publishing Company, Amsterdam, 1974

National Geophysical Data Center World Wide Web site,
<http://www.ngdc.noaa.gov/>, 1996

Mayr, H. G., Harris, I. and Spencer, N. W., Some Properties of Upper Atmosphere Dynamics, *Reviews of Geophysics and Space Physics*, 1978

Figures:

Figure 1

Simple diagram of instrument mechanism

Figure 2

Schematic drawing of REFLEX instrument

Figure 3

Initial (26) Spartan 206 orbital positions

Figure 4

Sample output from MSIS - E - 90

Figure 5

Graph of REFLEX instrument ion source densities

Figure 6

(top) REFLEX instrument source densities

(bottom) MSIS model ambient densities

Figure 7

New REFLEX instrument densities after ram effect correction

Figure 8

REFLEX and MSIS densities graphed

Figure 9

(2880) Spartan 206 orbital positions per minute

Figure 10

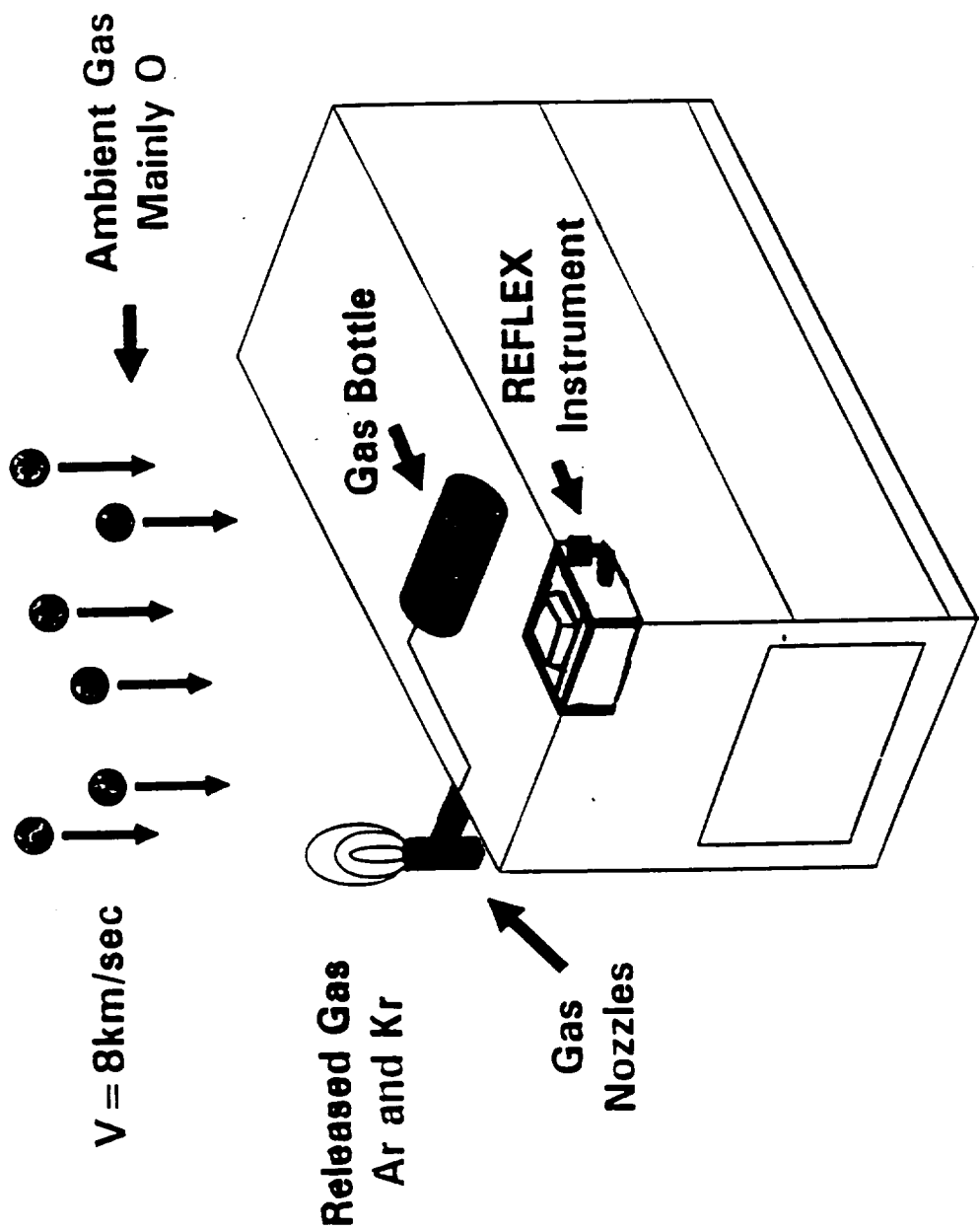
(540) Spartan 206 orbital positions for mission hours 13.5 through 22.0

Figure 11

New graph with improved MSIS resolution

Figure 12

Improved resolution with latitude extremes and equatorial crossings noted



REFLEX Instrument on Spartan Carrier

Figure 1

REFLEX INSTRUMENT

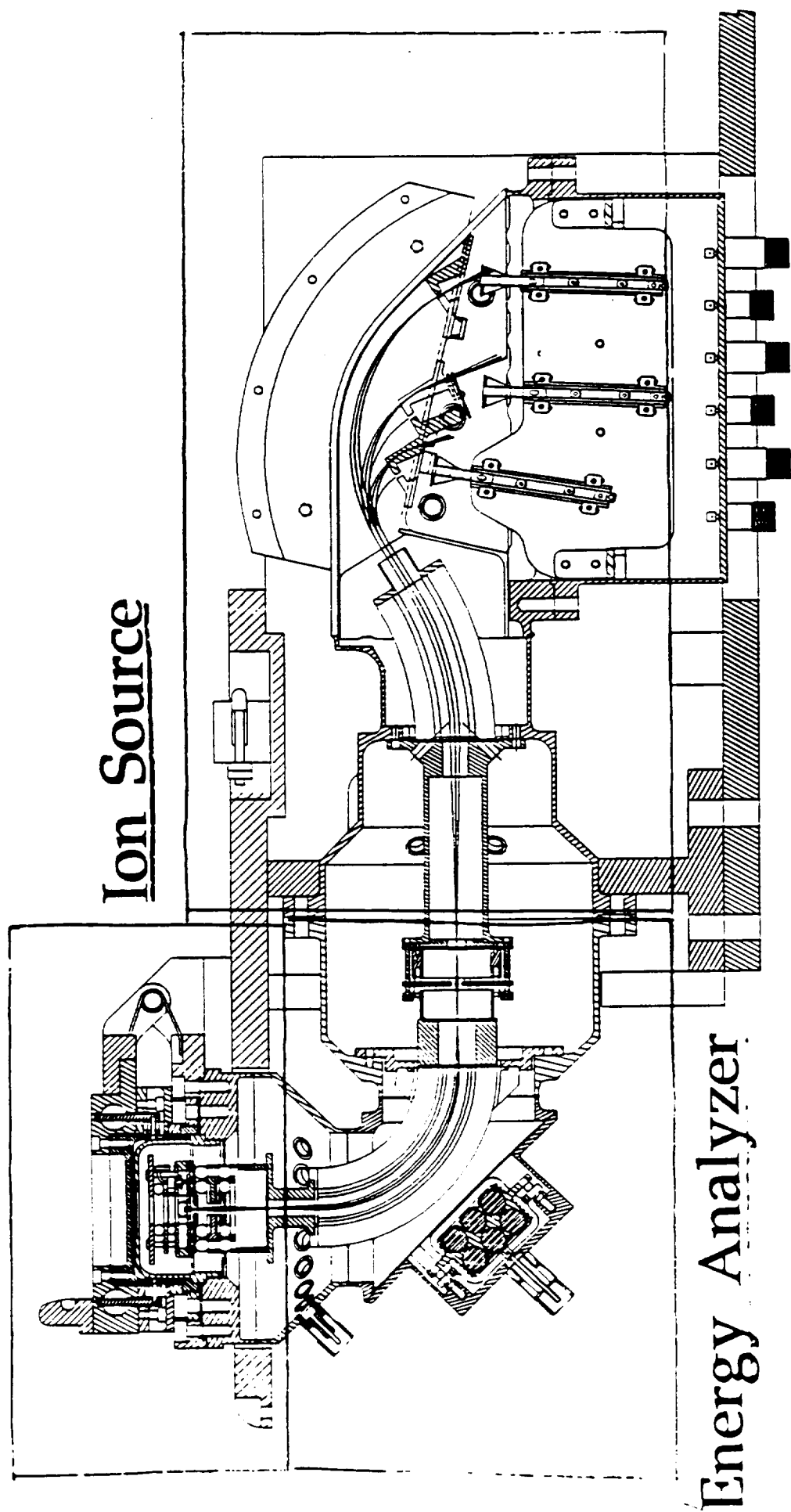


Figure 2

Mass Spectrometer

Figure 3

REFLEX orbit [Positions 1-26]:[Hours (total)] "

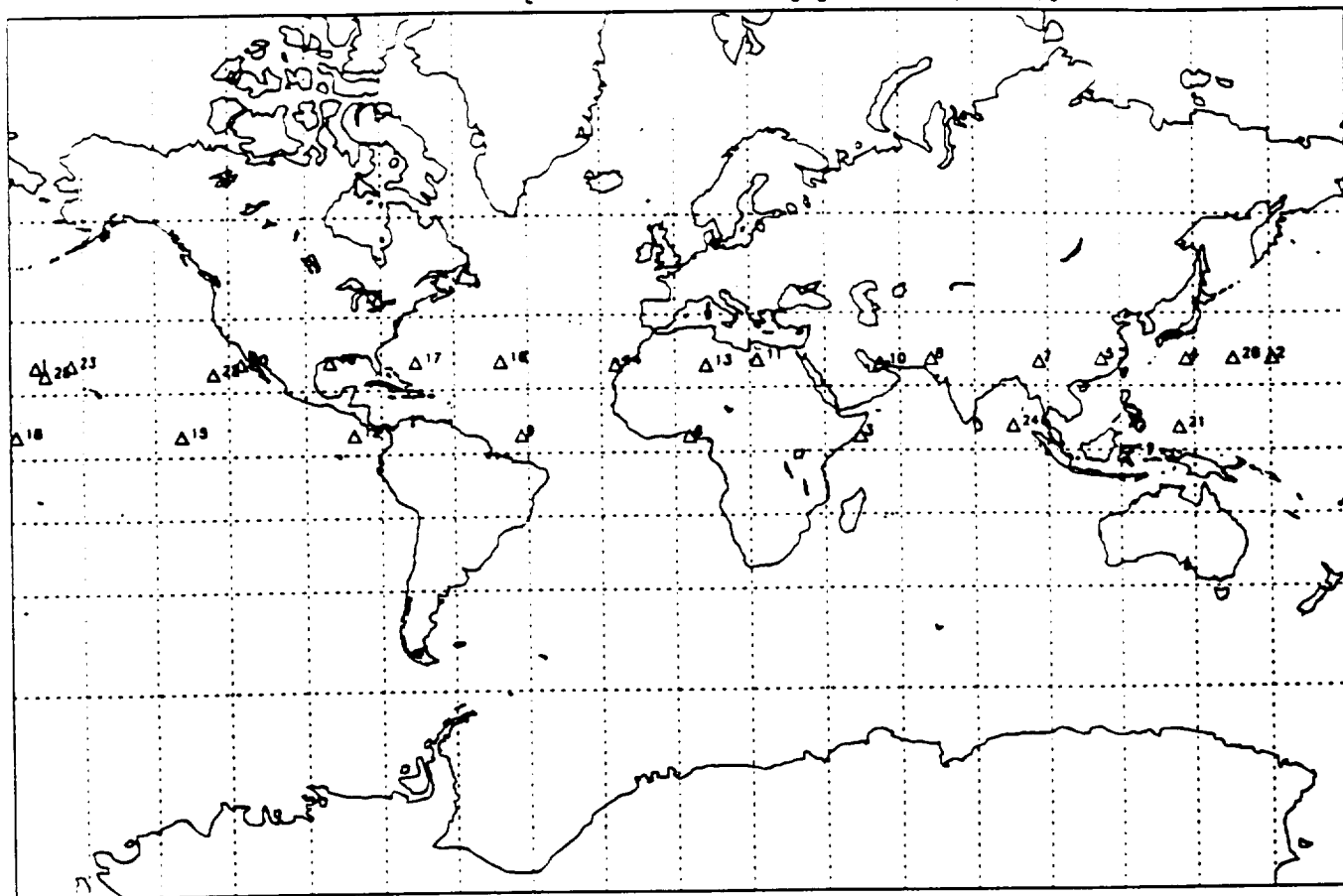


Figure 4

NSSDC

MSIS-E-90 Model

You submitted the following name/value pairs:

DATE: year=1996 month=01 day=14

TIME: hour=11.5344 UT

Geographical Latitude = -1.0

Geographical Longitude = 326.0

Altitude = 300.0

Results of MODEL calculations:

He Density cm-3	6.108E+06
O Density cm-3	3.086E+08
N2 Density cm-3	3.775E+07
O2 Density. cm-3	1.356E+06
Ar Density cm-3	3.771E+03
Total Density g/cm-3	1.014E-14
H Density cm-3	3.197E+05
N Density cm-3	3.190E+06
Neutral Temp. K	7.475E+02

Figure 5

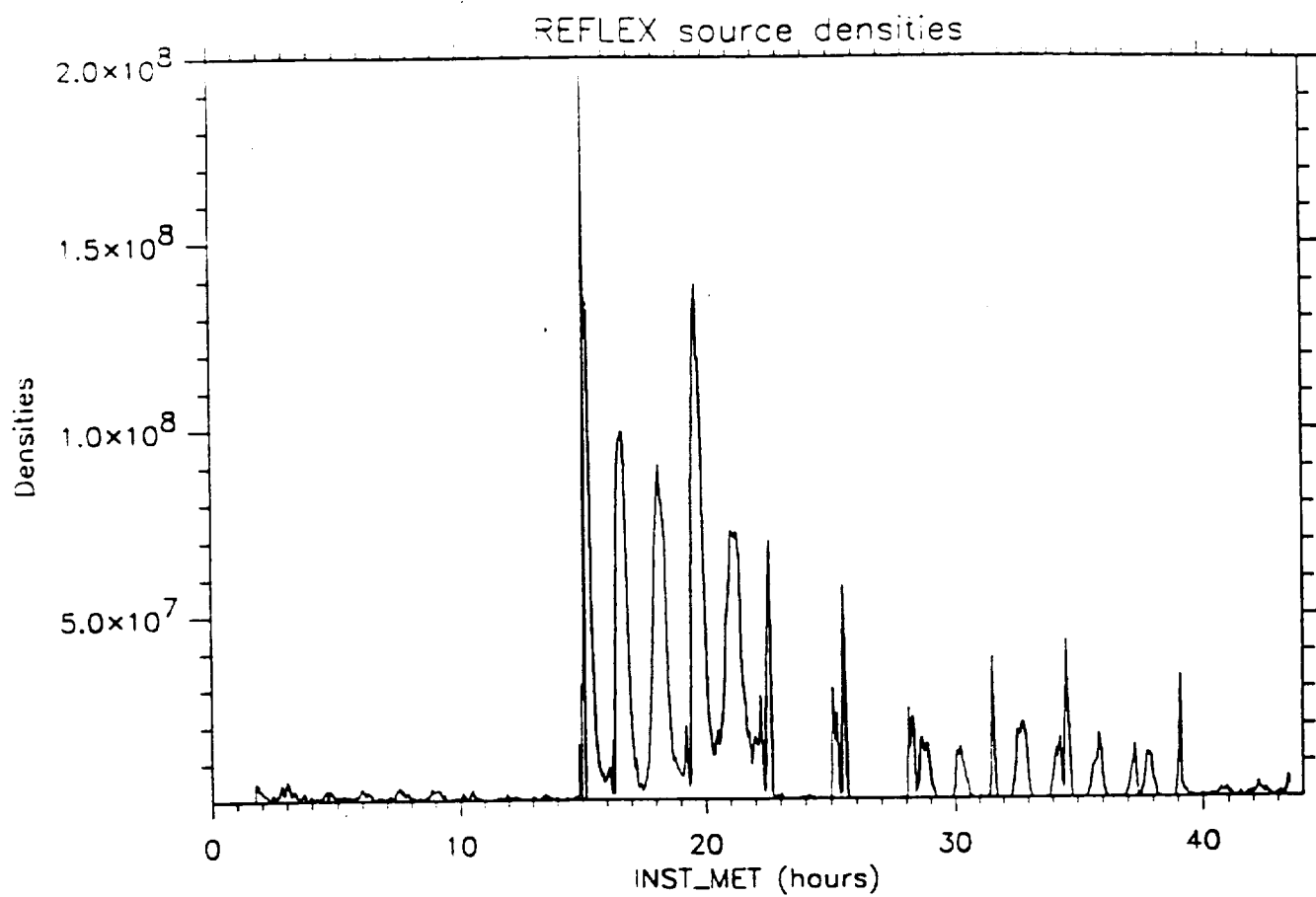


Figure 6

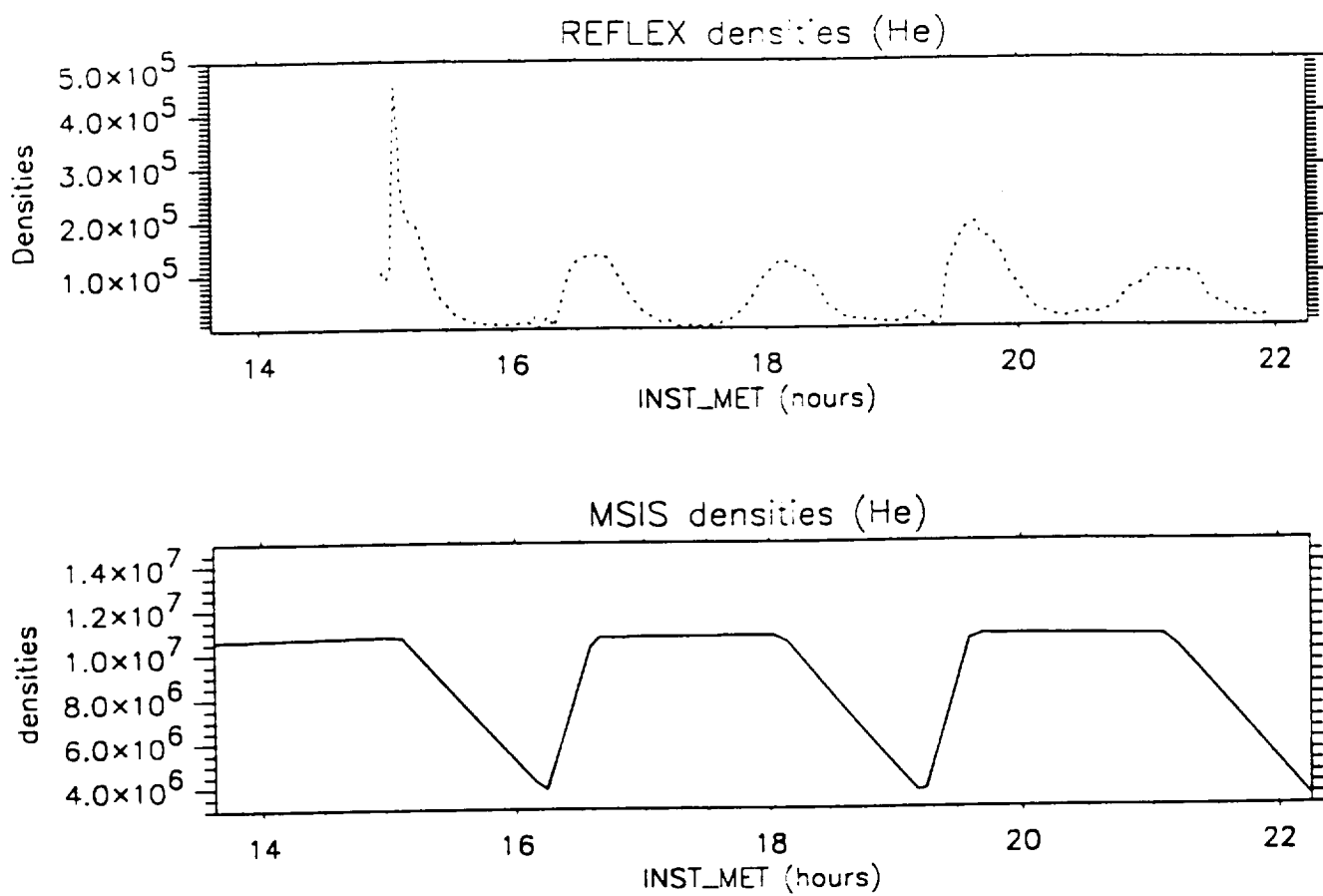


Figure 7

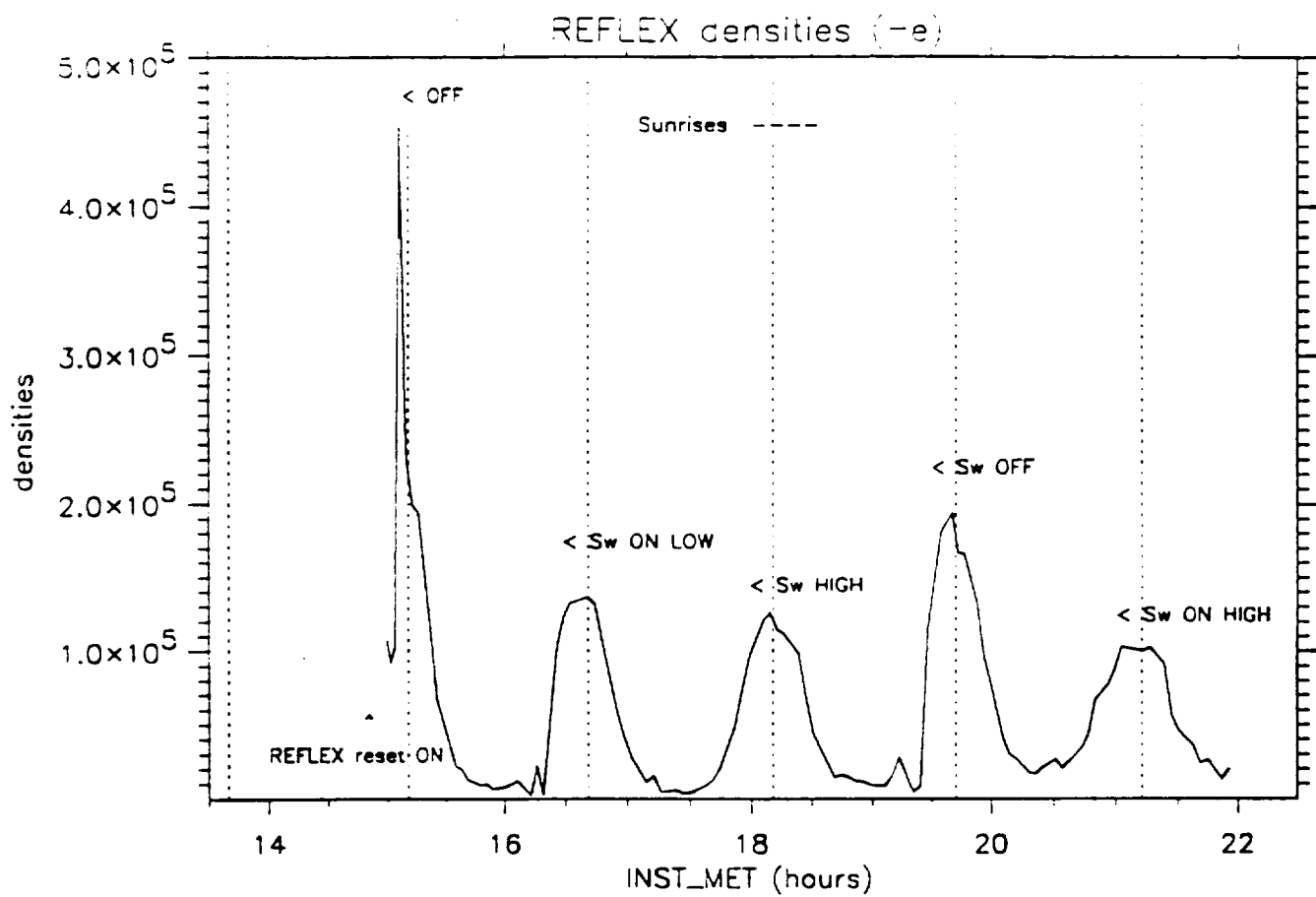


Figure 8

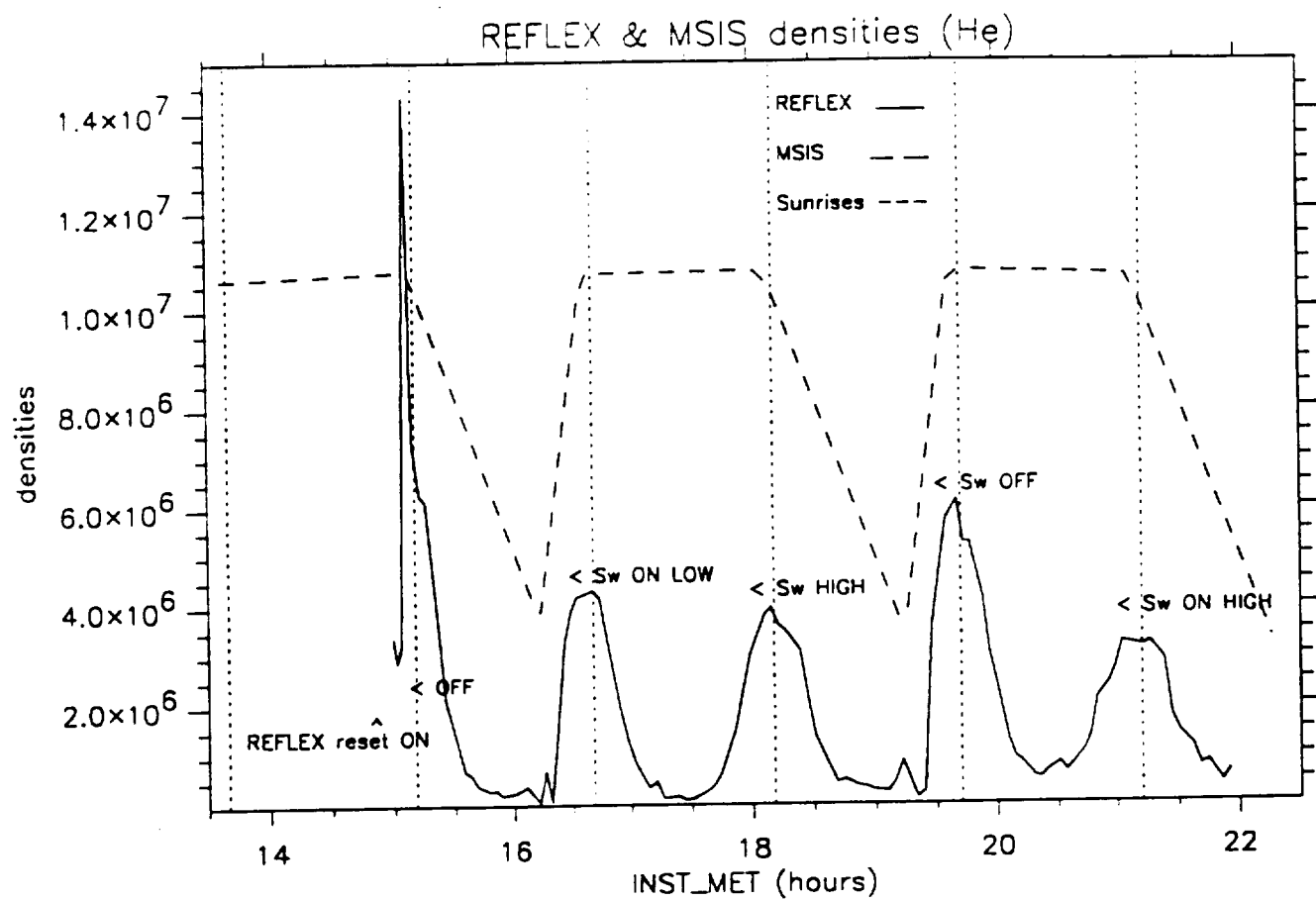


Figure 9

REFLEX orbit from expanded file [Hours (total)] "

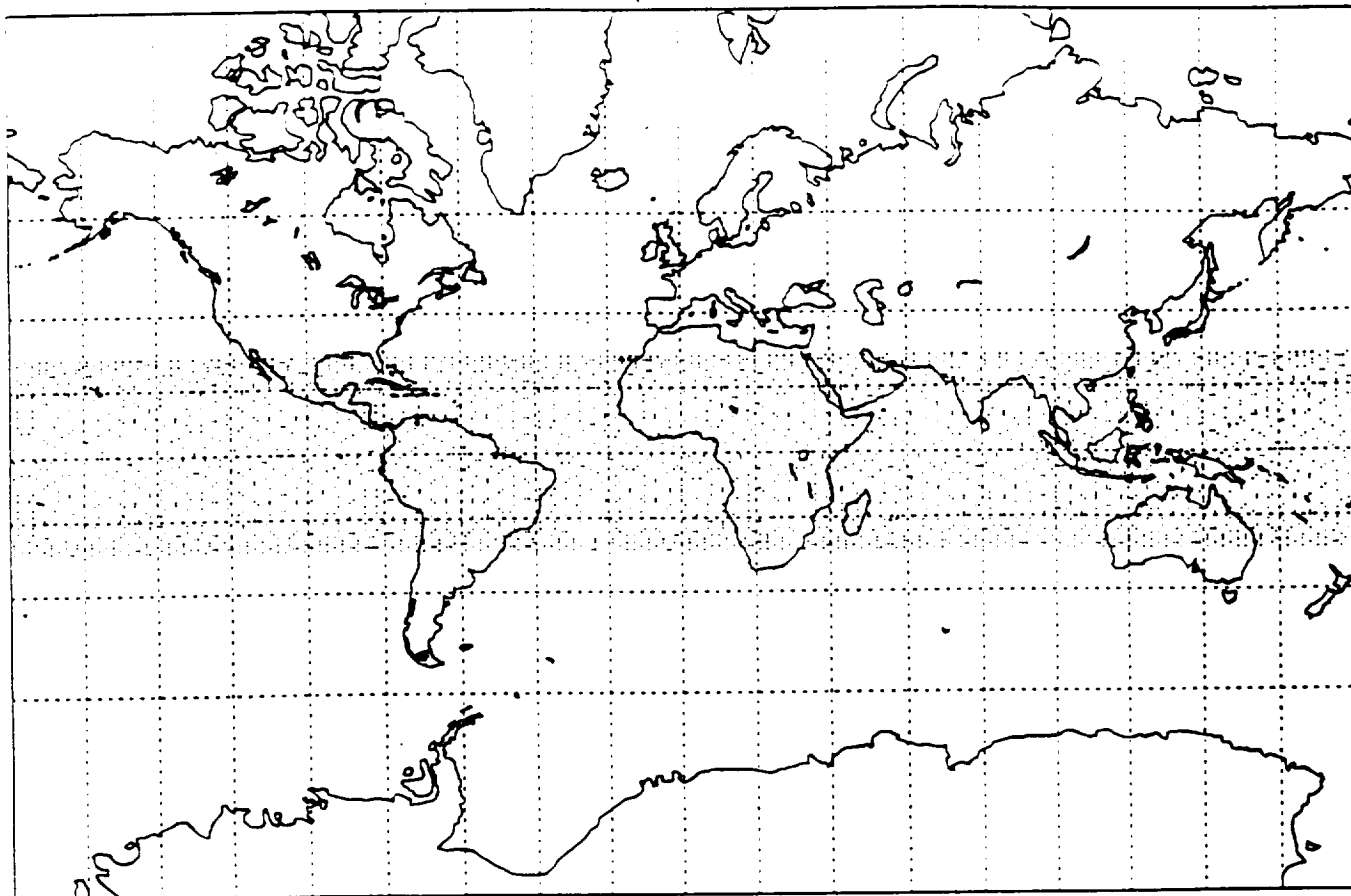


Figure 10

REFLEX orbit:[Hours 13.5-22]"

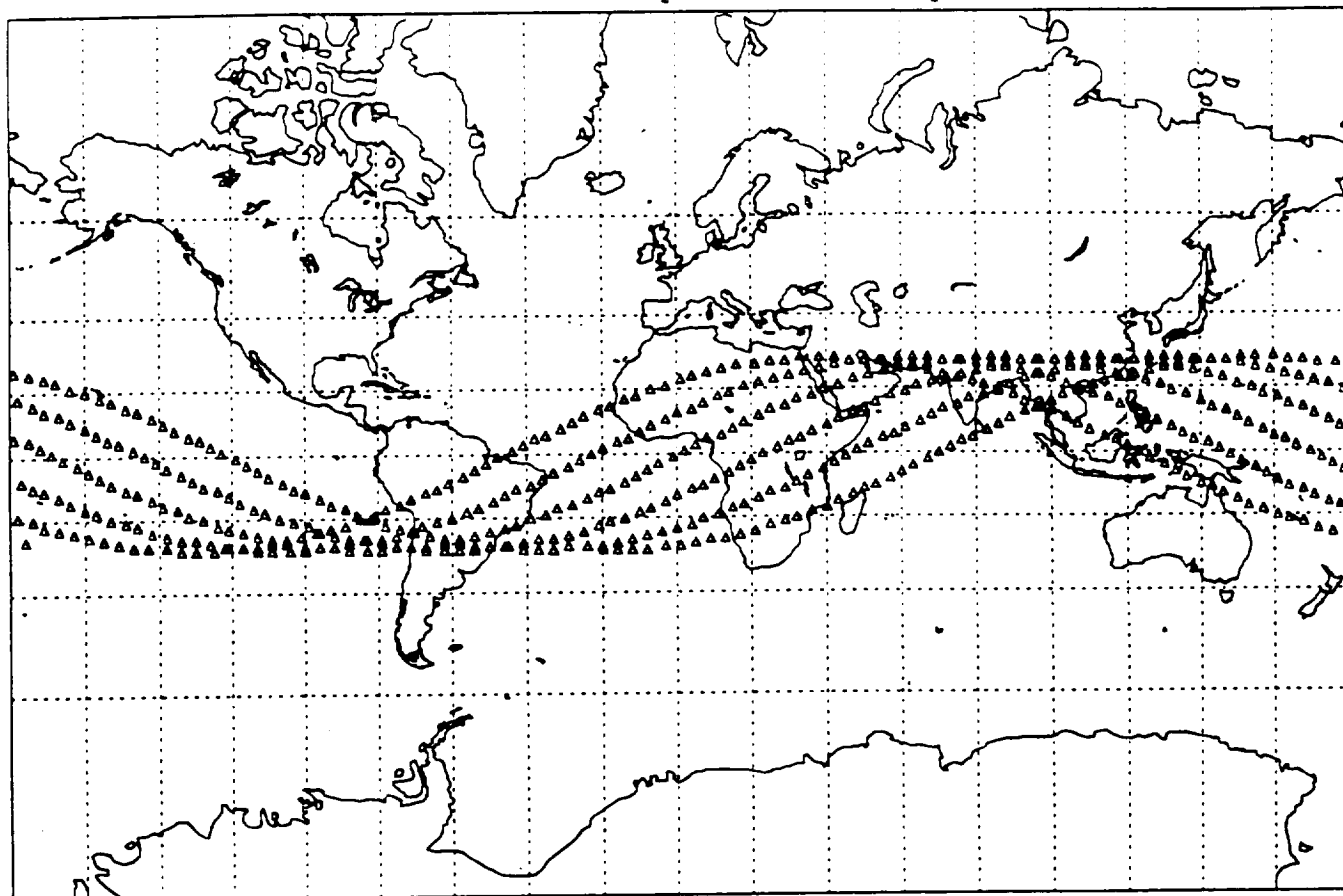


Figure 11

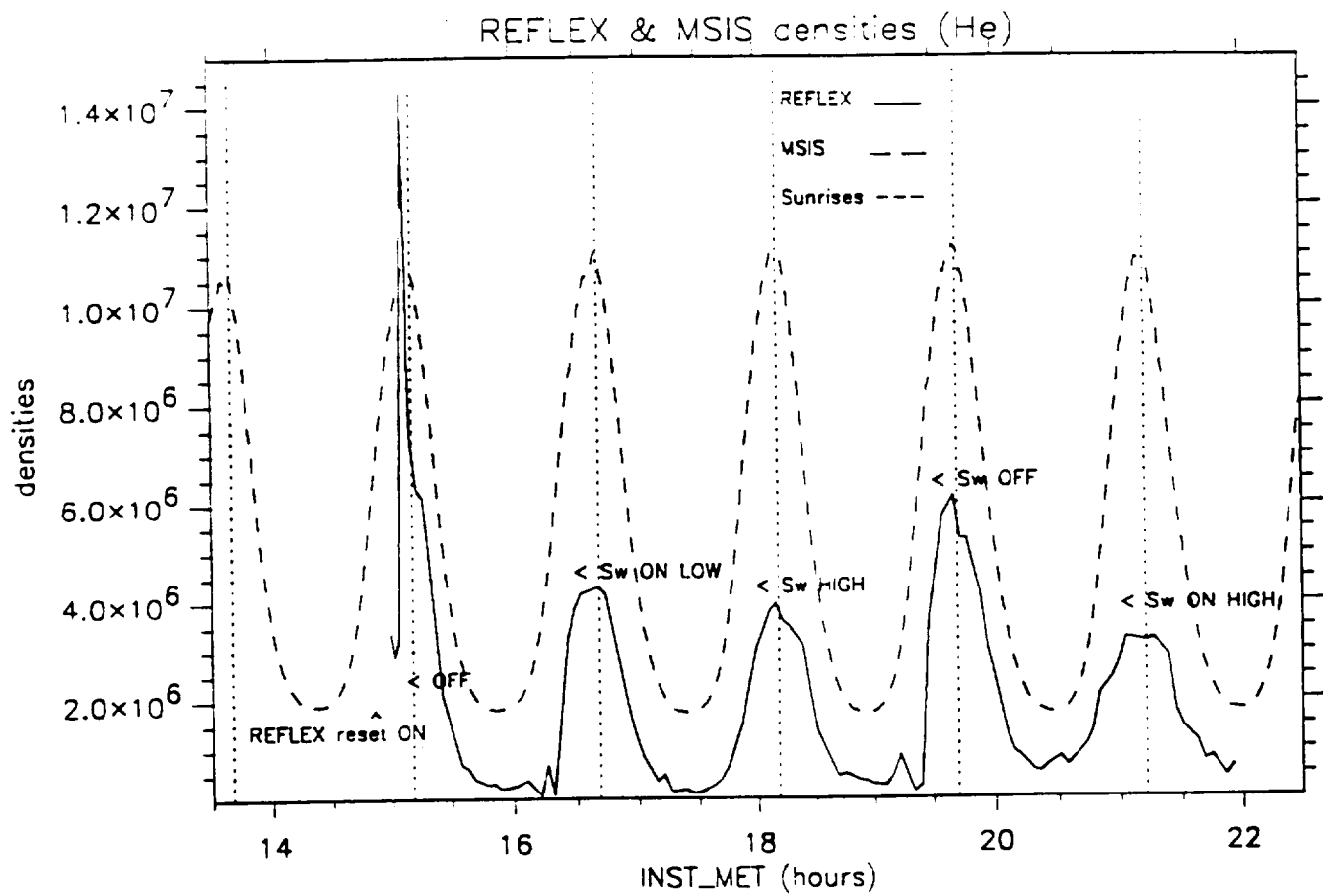


Figure 12

